A Synthesis of Oceanic Time Series from the Chukchi and Beaufort Seas and the Arctic Ocean, with Application to Shelf-Basin Exchange

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LONG TERM GOALS

My long-term goals are to understand the mechanisms of, and the variability in, exchanges between the shelves and interior Arctic Ocean. These exchanges are important in establishing the circulation, thermohaline, and potential vorticity structure of the Arctic Ocean. They are also crucial in the maintenance of the Arctic Ocean ice pack and therefore they potentially influence arctic climate. These goals underlie my motivation to:

1. provide an observationally based indication of the variability of the Arctic shelf-basin system, with an emphasis on the Chukchi and Beaufort seas;
2. understand the mechanisms of shelf-basin exchange and contribute to the development of future observational strategies based on this understanding;
3. promote comparison of models to observations by providing patterns and statistics from observations that are useful in model evaluation.

OBJECTIVES

This project is a retrospective study that uses existing data to address:

1. The variability of the shelf sources of the Western Arctic (particularly the Chukchi Sea) and the causes of that variability;
2. The principal mechanisms of exchange across the shelf and slope, with bounds on the rates;
3. The background circulation over the shelf, slope, and adjacent abyssal plain and their relation to shelf-basin exchange;
4. Secondary circulations over the shelf, slope, and adjacent abyssal plain and their variability. What are the sources of the water masses encountered along the slope;
5. Freshwater processing and transport over the shelf.

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APPROACH

To address these objectives, I am, in collaboration with Knut Aagaard (U. Washington), analyzing oceanographic time series of velocity, temperature, and salinity gathered from moored instruments from the Chukchi and Beaufort seas (primarily) but also from other sites around the Arctic Ocean. Where available and appropriate we will supplement these time series with supplementary hydrographic and chemical tracer data. These data were gathered with support from a range of agencies and programs in the U.S., including NSF, ONR, NOAA, MMS, ANWAP, and OCSEAP. We will capitalize on these measurements by constructing a new synthesis of the circulation and its variability. Our emphasis is on establishing the statistical properties of the measured flows and their temperature and salinity, as well as the dynamics that these statistics imply. We will also make the data sets available via a CD-ROM, on a home page, and/or through National Snow and Ice Data Center.

WORK COMPLETED

We are nearing completion on two manuscripts that describes the circulation over the outer Chukchi Sea shelf. The first addresses circulation paths, dynamics, and rates over the central Chukchi Sea shelf. The second focuses on dynamics and transports in Barrow Canyon in the Northeast Chukchi Sea.

RESULTS

We find that, on average, waters from Bering Strait move northward across the Chukchi shelf and into the Arctic Ocean through Herald Valley (in the western Chukchi Sea), in the channel to the east of Hanna Shoal (in the central Chukchi Sea) and through Barrow Canyon (on the northeast corner of the shelf). Over the outer Chukchi shelf the flow is northeastward, parallel to the isobaths, and opposite to the prevailing wind direction. We conclude that the sea-level slope between the Pacific and Arctic oceans primarily forces the mean flow field. The western and central flow paths advect biologically rich water onto the outer shelf and eventually eastward to the coast of Alaska. They also transport relatively dense shelf waters into the subsurface, eastward flowing boundary current along the Chukchi-Beaufort slope. Bathymetric steering of the mean flow exerts an important thermodynamic control on the shelf ice pack from spring through fall. At this time the warm waters advected along these paths melts the ice and forms large embayments in the ice edge.

While the mean flow is robust, flow variations are large. They are primarily wind-driven and the flow variability is coherent over spatial scales of order 300 km. (By contrast, the spatial coherence scales of the shelf flows along the west coast of the United States are several times smaller.) We also show that seasonal thermohaline processes can exert a significant influence on the shelf circulation. From fall through early spring horizontal density gradients (fronts) form whose strength and sign vary due to the seasonal effects of sea ice formation and advection of different water masses from the southern Chukchi shelf and northern Bering Sea. The length scale of these gradients is poorly resolved but they appear sufficient to force baroclinic currents having magnitudes comparable to the mean flow.

In some winters cold, hypersaline waters form within the extensive coastal polynyas created along the northwest coast of Alaska. Our data suggests that some of this dense water propagates along the bottom into the central Chukchi Sea as eddy-like features with speeds of 0.1 - 0.2 m s^{-1} and length scales of 10-20 km. The data are consistent with the model results of Gawarkiewicz and Chapman

(1995) that predict that dense water, formed within polynyas, generates vigorous eddies via baroclinic instability.

We find substantial interannual variability in wintertime thermohaline structure and production of dense water on the Chukchi Sea shelf. In winters that follow extensive fall ice-free conditions, shelf water column temperatures decrease to the freezing point by early December. However, water temperatures remain above the freezing point well into February in years when heavy ice covers the shelf in early fall. In years when there is extensive development of the coastal polynyas along the coast of Alaska, substantial volumes of hypersaline water (S>34) form in winter. Water with these characteristics is absent from the shelf in years when there is little polynya development.

We find that the long-term mean transport (based on ~ 6 years of direct observation) through Barrow Canyon (Figure 1) is ~0.3 Sverdrups, which is ~40% of the annually averaged mass transport through Bering Strait (Roach et al., 1995). The seasonal cycle of the mass flux is in phase with that in Bering Strait and is a maximum in summer and a minimum in winter. However, the proportion of the strait transport that exits through Barrow Canyon also seasonally. While ~60% of the Bering Strait outflow exits the shelf through Barrow Canyon in summer, less than 30% of the outflow drains through the canyon in winter. This implies a seasonal alteration in the flow paths of Bering waters moving across the Chukchi Sea.

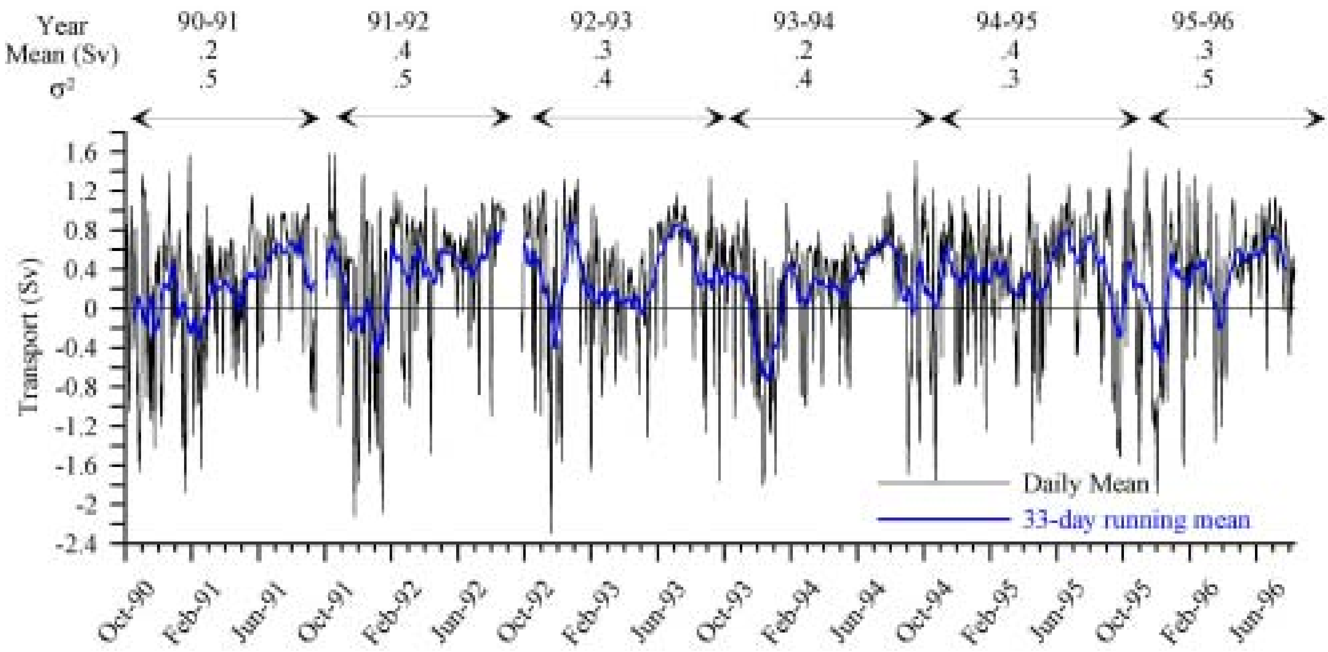

Figure 1. A six-year time series of the estimated transport through Barrow Canyon in the northeast Chukchi Sea. The annual means and variances (listed at the top of the figure) are derived from estimates beginning in October and ending the following September. The long-term average is 0.3 Sv and the 95% confidence limits are ± 0.1 Sv.

Our results indicate that the horizontal velocity shears between the center of Barrow Canyon and the eastern wall of the canyon are cyclonic (and measured midway along the longitudinal axis of the canyon) have a magnitude of generally < 0.2 of the local Coriolis value. This implies nearly linear flow dynamics. The small values of the shears also imply that insufficient anticyclonic vorticity is generated along the canyon wall to support D'Asaro's (1988) hypothesis mechanism for the formation of Arctic Ocean eddies.

We have documented that there are three branches along which Bering Strait water is advected across the Chukchi Sea shelf. By contrast Coachman et al (1975) suggested that there were only two branches; one through Herald Valley and the other through Barrow Canyon. Our finding of a third pathway is important because it suggests that much of the outer Chukchi Sea shelf is influenced by advection of waters from Bering Strait. These same waters could have important biological implications for they are generally rich in nutrients and (probably) dissolved and suspended marine-formed carbon.

We hypothesize that because the mean winds and ice drift also oppose the mean flow; there must be a large velocity shear within the upper portion of the water column over the shelf. The existence of these shears (and the nature of the shelf ocean boundary layer) needs to be investigated with an appropriate measurement program. Our findings suggest that bottom-confined eddies are a potentially significant transport mechanism on arctic shelves. These eddies might ventilate the halocline of the Arctic Ocean and they might be precursors to eddies that populate the Canada Basin.

Our findings also have implications for the pathways of Pacific Ocean waters into the Arctic Ocean. For example, it appears that the freshest fraction (in summer) flows predominantly through Barrow Canyon whereas the densest fraction (in winter) flows through Herald Valley. Because of the density difference of these water masses, they each ventilate different depths in the central basin. Moreover, the location on the Chukchi Sea slope where ventilation of Canada Basin waters differs seasonally. In winter, this occurs primarily through Herald Valley, while in summer this occurs primarily at Barrow Canyon. The preceding comments are based upon our evolving perception of this shelf's climatology. Of course, there are winters when very dense waters, formed in the polynyas along the northwest coast of Alaska, flow through Barrow Canyon and ventilate subsurface depths of the Canada Basin (Weingartner et al., 1998).

Our results also raise questions regarding forcing of the eastward flow along the Beaufort continental slope. The Barrow Canyon outflow should provide the most direct forcing for this flow. (The Herald Valley outflow might also contribute to alongslope forcing although there are other possible routes for this flow over the outer Chukchi slope.) Our results imply that this forcing is seasonal (strongest in summer and weakest in winter) and we anticipate that the along-slope flow is weaker in winter than in summer. We are examining this possibility with recently acquired current meter data from along the eastern Beaufort slope. Our velocity measurements do not support D'Asaro's hypothesis on the formation of Arctic Ocean eddies. However, they do not comprise sufficient evidence to refute this hypothesis.

TRANSITIONS

We have interacted with Glen Gawarkiewicz and David Chapman (both at Woods Hole) in the course of this work. Gawarkiewicz and Chapman are particularly interested in observations pertaining to eddylike features carrying dense water across the shelf.

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